Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Environmental Sciences 17 (2013) 547 – 556

Procedia
Environmental Sciences

The 3rd International Conference on Sustainable Future for Human Security
SUSTAIN 2012

Energy efficiency to reduce poverty and emissions: a silver bullet or wishful thinking? Analysis of efficient lighting CDM projects in India

Jorge Gómez-Paredes*, Eiji Yamasue, Hideyuki Okumura, Keiichi N. Ishihara

Graduate School of Energy Science, Kyoto University,Yoshida-honmachi,Sakyo-ku, Kyoto 606-8501,Japan

Abstract

Energy efficiency is a major strategy to reduce greenhouse gas emissions. Thus, it is being implemented as part of the Kyoto Protocol's Clean Development Mechanism (CDM). Efficient lighting CDM projects claim to alleviate poverty and reduce emissions, while also aiding buyers of Certified Emission Reductions credits (CERs) to meet their abatement targets. Yet, as energy savings calculations do not account for behavioural responses, which cause "rebound effects", a limited analysis may lead us to be overoptimistic about these projects' environmental accomplishments. This study estimates the impact of the expenditure of monetary savings (understood as "poverty alleviation") on the reduction targets of two CDM projects. Results suggest that the projects may, in fact, reduce electricity consumption further than expected; however, in terms of CO_2 emissions, results vary. Whereas in one case the effect may not significantly affect the CO_2 target, in the other it may compromise around 8% or 19% of it, consequently leading to an overestimation of CERs. A wider perspective of analysis is needed if energy efficient projects are to be held as a "silver bullet".

Keywords: Rebound effect, Jevons paradox, efficient lighting, total energy requirements, Clean Development Mechanism (CDM)

1. Introduction

For years energy efficiency has been the cornerstone of most countries' energy conservation strategy; nowadays it is also considered to be "often the most economic and readily available means of reducing

* Corresponding author. Tel.: +81-909-877-9869; fax: +81-075-753-5464.
E-mail address: jorge.gomez.paredes@gmail.com

doi:10.1016/j.proenv.2013.02.070

greenhouse gas emissions [1, p.9].” More than half of the World’s CO_2 emissions reductions by 2035 are expected to be achieved by enhancing energy efficiency alone [2]. Given that energy demand is rapidly rising in fast growing economies, a number of energy efficiency projects are being targeted to countries like India.

India’s electric power demand is expected to triple by 2051, growing annually at around 10% [3]. With the majority of electricity generation based on coal-fired plants and considering that about 25% of the country’s electricity demand comes from households [4], many projects aim at enhancing energy efficiency in homes, such as by replacing conventional incandescent light bulbs (GLS) with long-life Compact Fluorescent Lamps (CFLs). Some of these projects are part of the Kyoto Protocol’s Clean Development Mechanism (CDM) scheme, which generates tradable Certified Emission Reductions (CERs) credits. The appeal of these demand-side efficient lighting CDM projects is that they are to reduce emissions while simultaneously alleviating poverty and aiding CERs’ buyers to meet their emission reduction targets, a win-win-win solution. However, these CDM’s analysis is limited in terms of scope and time. It ignores the wider concept of households’ Total Energy Requirements (TER), which is an essential consideration when evaluating households’ energy demand [5]. The TER’s perspective describes households’ total energy and related CO_2 emissions as resultant from their consumption of energy commodities and also from the embodied energy (and CO_2 emissions) in all consumed goods and services. Under the TER’s logic, whereas at the time of implementation the projects may indeed reduce households’ direct energy (electricity) requirements and simultaneously generate monetary savings from lower electricity bills (what is understood as “poverty alleviation”), the later expenditure of such savings may claim back some of the energy reductions, a phenomenon commonly referred as “rebound effect”.

A number of researches have argued about the need to include rebound effects in CDM projects’ calculations [6]-[9]. Even so, no study has thus far attempted to estimate any rebound for a CDM project. Furthermore, whether we can remain assured that enhancing energy efficiency will deliver its expected outcomes, that it can be used to tackle both poverty and emissions simultaneously with no tradeoffs, and that these projects’ CERs are not overvalued, constitute relevant issues not just for CDM’s investors and CERs’ purchasers, but for policy-makers and society in general. In this view, this paper explores how much of the targets of two efficient lighting CDM projects could be compromised by the expenditure of monetary savings (Fig. 1). In line with the projects’ targets, we calculate rebounds in terms of electricity and in terms of CO_2equivalent (CO_2e) emissions by considering the changes in households’ total electricity consumption and total CO_2e emissions. Outside of the scope of this study, however, is the estimation of the long-term effect of these projects on the households’ total requirements, a valid concern when dealing with efficiency improvements in evolving complex adaptive systems [10]. Nonetheless, this study offers an insight into the issues and challenges at hand.

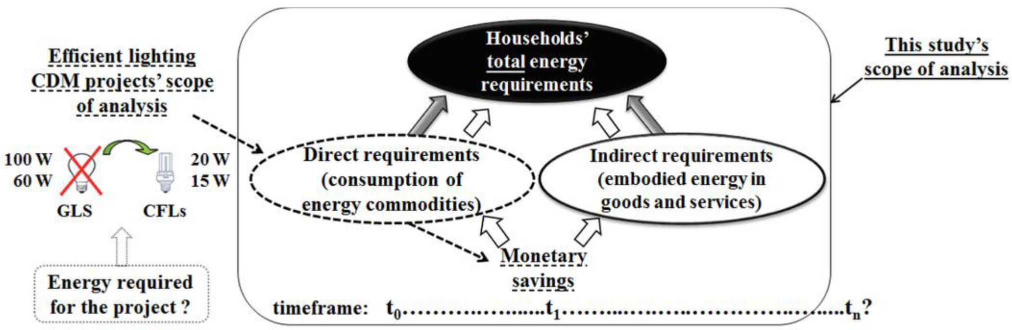

Fig. 1. Scope of analysis of efficient lighting CDM projects, and scope of this study

2. Methodology

2.1. Input-output analysis, consumer surveys and rebound effects

Input-output analysis (IOA) is a macroeconomic tool developed by Wassily Leontief, which captures the interrelationships among economic sectors of an economy [11]. As such, it is applied in net energy analysis in order to determine TER [12]. The basis of IOA stems from an input-output transaction table (IOTT) in which a square matrix **Z** records all the inter-industrial monetary transactions of an economy. In **Z**, each element z_{ij} describes the input of industry-sector i that is used in the production of industry-sector j. From **Z**, a matrix of technical coefficients **A** is constructed by dividing each element z_{ij} by the correspondent industry's total output x_j. Thus, the elements of **A** represent inputs per unit of total output a_{ij} (1). The matrix **A** forms part of the basic input-output identity (2), which expresses that the total output **x** of an industry is equal to the final demand of its products **y** plus all the intermediate demand **Ax** related to that final demand. Solving for vector **x** gives Leontief's equation (3), where the elements of the $\mathbf{(I-A)^{-1}}$ matrix constitute coefficients that include all the intermediate demand for a unit of final demand and, thus, allow for the calculation of total requirements.

$$a_{ij} = \frac{z_{ij}}{x_j} \tag{1}$$

$$Ax + y = x \tag{2}$$

$$x = (I - A)^{-1} y \tag{3}$$

For environmental applications, a hybrid matrix **Z** is constructed by replacing monetary transactions with equivalent transactions in physical units. In order to calculate the embodied electricity in different commodities we constructed a hybrid matrix **Z** based on the latest available Indian IOTT. Monetary transactions of the electricity row-sector were replaced by equivalent transactions in GWh, in accordance to the total domestic electricity consumption of the same fiscal year. The amount consumed by power stations auxiliaries was included as the electricity sector's own use; the rest was distributed among the different column-sectors in proportion to their share of the total monetary output of the electricity sector. From **Z**, we calculated a hybrid matrix **A** and then a hybrid Leontief's inverse matrix, where the elements in the electricity-row sector corresponded to the total electricity intensities of the different commodities. We then multiplied these intensities with households' expenditure data, which yielded their total (direct and indirect) requirements [13].

In order to estimate households' CO_2e emissions, a household's total emissions was understood as the sum of the emissions due to its electricity consumption, plus the emissions from its direct consumption of fuels, plus the emissions embodied in the consumption of all other non-energy commodities. Disaggregating this concept gave equation (4), where ε corresponds to the amount of purchased electricity, I_e is the previously calculated electricity intensity of electricity, G_e is the local grid emission factor, Q_f corresponds to the amount of purchased fuel f, I_f is the corresponding fuel's combustion emission factor estimated from the Intergovernmental Panel on Climate Change (IPCC) data (see appendix A), S_i is the monetary expenditure on a non-energy commodity i, and I_i is the corresponding CO_2 intensity as calculated by Goldar et al. [14] from the same IOTT than this study[a].

$$M_t = (\varepsilon \cdot I_e \cdot G_e) + \sum_f (Q_f \cdot I_f) + \sum_i (S_i \cdot I_i) \quad (4)$$

Prior to these calculations, each consumer item in the expenditure survey was matched to a commodity in the IOTT, in accordance to the each IOTT sector's specification [15]. Additionally, Consumer Price Indexes were used in order to correct for price changes between the time of the surveys and the IOTT data. Lastly, given that the IOTT's transactions are in factor cost whereas the expenditure data is recorded at purchase prices, expenditure amounts were corrected by subtracting taxes and adding subsidies.

In order to calculate rebound effects, households were divided into rural and urban groups and into income quintiles using total expenditures as a proxy of total income. This separation was done given that consumption patterns tend to differ among these groups due to distinct lifestyles and access to commodities. The monetary savings *S* resultant from the use of CFLs were calculated by multiplying each group's electricity expenditures S_e before the implementation of the CDM projects, by the ratio between the projects' expected reductions ε_r and the amount of electricity purchased by all the households in the project ε_t (5). Then, in a first scenario ("all commodities" scenario), we distributed the savings back into consumption items according to each item's share of total expenditures; thus, in accordance to each group's consumption patterns. In a second scenario ("food & cooking fuel" scenario), considering Engel's law which states that poor households spend most of their budget on food [16] and also in view that food items and fuels are among the most subsidized and thus affordable commodities in India, households were additionally grouped by their cooking fuel, and then monetary savings were allocated only on food items and cooking fuels, according to their food to fuel ratio.

Finally, rebound effects were estimated in terms of electricity and in terms of CO_2e emissions as in (6). Where *RE* is the net rebound, *ER* is the expected electricity (emissions) reductions from the CDM projects, TE_B is the households' total electricity requirements (total emissions) before the use of CFLs, and TE_A is the households' total electricity (total emissions) after; i.e. considering the electricity reductions from the use of CFLs and those increased by the expenditure of monetary savings. Hence, rebound values represent the percentage of the expected reductions that may not be achieved by the projects.

$$S = S_e \left(\frac{\varepsilon_r}{\varepsilon_t} \right) \quad (5)$$

$$RE[\%] = \left[\frac{(ER - (TE_B - TE_A))}{ER} \right] \cdot 100 \quad (6)$$

---

[a] The units of the emission intensities shown in Goldar et al. correspond to 10 tonnes of CO_2 per million Indian rupees (10tCO_2/MRs), instead of kilo-tonnes per million rupees (ktCO_2/MRs) as it is stated in their publication. This typing mistake was confirmed through correspondence with the author.

2.2. Case studies

The considered projects were the “Visakhapatnam (India) OSRAM CFL distribution CDM Project” and the “Yamunanagar & Sonipat (India) OSRAM CFL distribution CDM Project”; both implemented in 2009 for a period of ten years. The projects aim at average annual electricity reductions of 32.93 GWh (Visakhapatnam) and 52.05 GWh (Yamunanagar & Sonipat), which correspond to 27.99 ktCO_2e and 41.64 ktCO_2e, respectively. This equivalence is based on grid emission factors of each locality: 0.85 kgCO_2e/kWh for the former [17] and 0.80 kgCO_2e/kWh for the latter [18]. India was chosen considering that it is the second largest host country of CDM projects and the first for projects on lighting efficiency.

The households’ expenditure data used in this study was taken from an equal number of households than the total number participating in each project; namely: 669,036 from the Visakhapatnam district, and 377,854 from Yamuna Nagar and Sonipat districts, all of which use electricity as their main source for lighting. Since these projects are targeted to poor households and are implemented in rural and urban areas, the households were selected from the “poorest” to the “richest” according to their total expenditure budgets, and from both regions according to the districts’ demographic distribution (54% from rural and 46% form urban areas in Visakhapatnam; 73% form rural and 27% from urban areas in Yamuna Nagar & Sonipat).

2.3. Data sources

We used India’s 2003-04 commodity-by-commodity IOTT [15]. Data on electricity consumption by Indian economic sectors in 2003-04 was taken from national reports [4]. Data on households’ consumption was taken from the 64th Round Consumer Expenditure Survey, 2007-08 [19]. Indian Consumer Price Indexes for the financial years 2003-04 and 2007-08 were taken from Indian statistics [20]. Calorific values of fuels and emission factors for stationary combustion corresponded to those published by the IPCC [21]. The embodied CO_2 emissions in Indian commodities were those calculated by Goldar et al. [14]. Finally, data on the CDM projects was taken from the UNFCCC-CDM Project Design Documents No. 1754 and No. 2457 [17],[18].

2.4. Assumptions and limitations

The main assumptions of this study correspond to those inherent in IOA, such as linear production functions among each industry's outputs and its required inputs. For an explanation of this and other related assumptions see the Handbook of Input-Output Table Compilation and Analysis [11]. Additionally: In our two scenarios we have assumed that savings are to be spent in accordance to households’ current expenditure patterns. In our first scenario we assumed equal income elasticities for all commodities, and in our second scenario we assumed a linear relation between food and cooking fuel. On the other hand, we did not assume the carbon neutrality of emissions from biomass in the view that such assumption not always holds [22] and that it is critical in this analysis given the extensive consumption of traditional fuels among Indian households [23]. Thus, our rebound calculations include emissions from both, fossil and non-fossil fuels.

It is due to considerable lack of available data that our scenarios assumptions had to be made and that methods to determine the likely distribution of monetary savings, such as demand-system models, could not be applied. Also, it should be noticed that our calculations of the CO_2e emissions from the households’ consumption of fuels do not include the fuels’ embodied emissions, but only those from their combustion; and that Goldar’s CO_2 intensities do not account for other greenhouse gasses. Therefore, our emissions rebounds may be underestimations. Further research should overcome these limitations.

3. Results

The electricity intensity of the electricity commodity was calculated to be 1.145 kWh/kWh, which indicates that for each kWh used by households, electricity utilities need to generate an additional 0.145 kWh. This 14.5% extra constitutes the intermediate consumption needed for delivering that one kWh to final demand. This value is remarkably similar to the one estimated by Pachauri [23] using the previous version of Indian IOTT. It follows that for every kWh that households "save" an extra 14% is also reduced, which constitutes additional electricity and emission reductions than what the projects have originally estimated, and which consequently offsets the rebounds. The calculated electricity intensities of all commodities are shown in Appendix B.

Total monetary savings were calculated to be in the order of 67.90 million rupees per year (MRs/year) for the Visakhapatnam project; and 195.03 MRs/year for the Yamunanagar & Sonipat project (Table 1).

Table 1. Monetary savings from electricity savings

Project	No. of households	Electricity purchased (GWh/year)	Expected electricity savings (GWh/year)	Expenditures in electricity (MRs/year)	Monetary savings (MRs/year)	Per household savings' range (Rs/year)
Visakhapatnam	669,036	413.14	32.93	852.02	67.90	30 to 236
Yamunanagar & Sonipat	377,854	448.91	52.05	1,682.12	195.03	263 to 1,267

These values correspond only to a maximum of 236 Rs. and 1,267 Rs. per household, respectively. Nonetheless, these little amounts have to be seen in the context of these households' marginal consumption levels and bearing in mind that many of them even fall below India's poverty line[b] (Fig. 2). The allocation of these savings into different consumption items, considering the distribution of expenditures of each group (Fig. 2), and on food items and the different fuels used for cooking (Fig. 3), yielded the rebounds in the "all commodities" and "food and cooking fuel" scenarios, respectively.

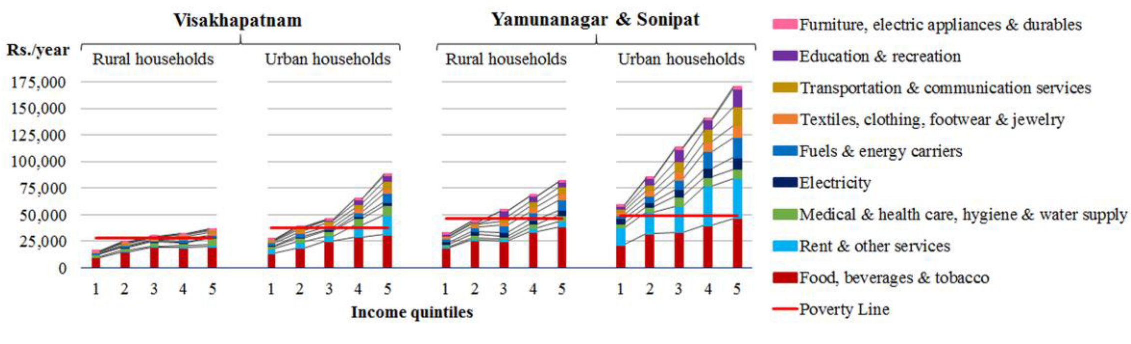

Fig. 2. Per household average annual expenditures

[b] India's poverty line is set at 22.42 Rs./day per person in rural areas and 28.35 Rs./day per person in urban areas [24]. The "poverty line" shown as reference in Fig. 2 was calculated in a per household basis considering the households' average size (Visakhapatnam: 3.39 persons in rural areas, and 3.60 in urban areas; Yamunanagar & Sonipat: 5.64 persons in rural areas and 4.72 in urban areas).

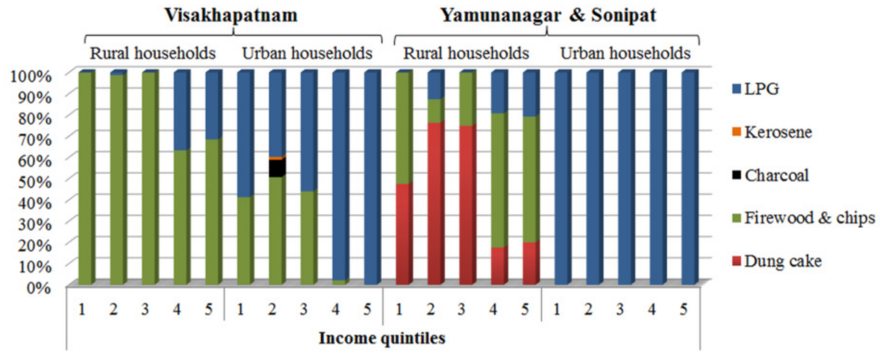

Fig. 3. Percentage of households of each income quintile-group by cooking fuel

The rebound effects in terms of electricity, for both projects, resulted negative; which means that the amount of electricity demanded by the expenditure of savings did not surpass the additional electricity reductions explained before. Thus, the projects' may actually reduce electricity consumption more than originally expected. However, in terms of CO_2e emission results varied (Fig. 4). In the case of the Visakhapatnam project, the additional emissions reductions nearly offset all the rebound emissions. The net rebound (calculated rebound minus additional reductions) was around 4% in both scenarios. Yet, considering that CERs for these CDM are issued deducting 2% from each projects' targets [17],[18], no significant amount of CERs would be overvalued in this case. The reason why the rebound values are similar under both scenarios may be explained by the fact that most of these households' expenditures are already being used for food purposes; thus, there is no much difference in allocating savings in all commodities and only on food and cooking fuel.

On the other hand, for the Yamunanagar & Sonipat project, the net rebounds were in the order of 19% ("all commodities" scenario) and 8% ("fuel and cooking fuel" scenario). Considering the 2% adjustment, CERs would then be inflated by around 17% or 6%.

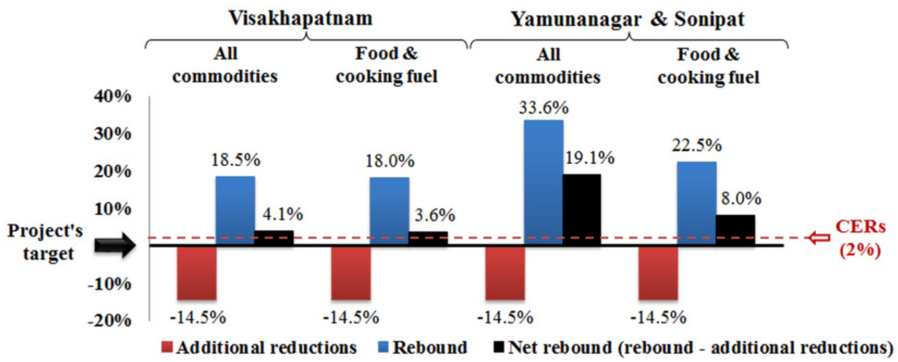

Fig. 4. Results of CO_2e emissions rebounds

4. Discussion

It is important to point out that our study has not included other emissions linked to the projects, which would contribute to higher rebound values (see section 2.4). Additionally, the CO_2e emissions from the energy required for the production of CFLs and the implementation of these projects is not being considered (Fig. 1), which should be taken into account for an assessment of the projects' CO_2e reduction achievements from a lifecycle perspective. Also beyond this study's scope was the attempt to assess the projects' long-term effects (in view of their 10-year lifetime). E.g., some researches point out that by being able to afford longer hours of lighting households may have "greater flexibility in time allocation throughout the day and evening, and enhance the productivity of education efforts [25, p.82]"; all which in turn could impact their consumption levels and patterns and, thus, generate changes in their TER. Nevertheless, our simple analysis has suggested that by the sole distribution of monetary savings among the commodities that they currently consume some of the CERs could already be compromised.

Results, however, have shown significantly different CO_2e rebounds for each project. Although different consumption patterns and commodities prices played a role in this regard, the main reason behind this difference is that households in the Yamunanagar & Sonipat project have greater monetary savings to spend than their counterparts. This constitutes a clear link between the rebound effect and poverty alleviation, and exposes the challenge of liberating poor households' suppressed demand while attempting to reduce emissions linked to consumption, as well as a trade-off between these two goals when pursued through efficiency improvements.

Avoiding the rebound by restraining the additional demand for goods and services, via regulation or taxation, would ensure the effectiveness of energy efficiency to curb emissions [26]. However, such an approach is clearly not morally applicable to the case of poor households. Thus, if the rebound effect in projects targeted to the poor is not only to be allowed, but it is actually desirable, then the main dilemma falls in the calculation of CERs. While on the one hand, accounting for rebound effects in CDM projects will mean less CERs per project, thus lowering their economic attractiveness [6]; on the other, since CERs allow their buyers to meet or to expand their emission caps [27], not doing so bears the risk of not reducing global emission as expected or even concealing their increase, hence the importance of considering rebounds. We must be aware, however, that modelling the human response to efficiency improvements and calculating the *total* rebound effect may be significantly challenging [25] or simply impossible without empirical data (post implementation) [28].

5. Conclusions

Whereas it is difficult to draw general conclusions from this exercise, there are reasons for concern on the overestimation of CERs. Our analysis showed that, considering indirect requirements, the CDM projects could in fact reduce electricity consumption further than is estimated; however, in terms of CO_2e emissions, the target of the project that generates more monetary savings (Yamunanagar & Sonipat) may be compromised by around 8% or 19%. This suggests that those CERs would be overvalued in similar amounts. Although these results could then imply that the majority of the expected emissions reductions from these projects will still be accomplishable, such a claim is problematic, for our analysis is also limited. What will the long-run impact of more efficient lighting on poor households' TER be, is debatable; so is the total emissions balance of these projects. Nonetheless, this study has exposed the inherent problem of energy efficiency, and of allowing those in need to increase their marginal consumption while also aiming at curbing their carbon emissions.

Since reducing poverty and greenhouse gasses are among the most important challenges that we face today, and both are needed for a sustainable human society, enhancing energy efficiency in poor households regardless of the size of the rebound seems beneficial. In fact, in this context, the expenditure of monetary savings, i.e. the rebound effect, is a desirable outcome. The relevant question then is: Should these projects generate CERs, involving the emissions reduction efforts of others (CERs' buyers)?

A wider degree of analysis is needed if energy efficiency is to be held as a "silver bullet".

References

[1] Tailor P. Worldwide trends in energy use and efficiency. International Energy Agency. Paris: IEA; 2008.

[2] Tanaka N. World energy outlook 2010. International Energy Agency. Paris: IEA; 2010.

[3] Asif M., Muneer T. Energy supply, its demand and security issues for developed and emerging economies. *Renewable and Sustainable Energy Reviews* 2007; **11**: 1388–1413.

[4] Ministry of Statistics and Programme Implementation (MOSPI). *India statistics, industry sector, chapter 16*, *Energy*. [Online]. Available: http://mospi.nic.in/Mospi_New/site/India_Statistics.aspx

[5] Wilting H.C., Biesiot W. Authors of *Household Energy Requirements* in *Green households? Domestic consumers, environment and sustainability*. Noormand K.J, Uiterkamp T.S., Ed. London: Earthscan; 1998.

[6] Shrestha R., Timilsina G. The additionality criterion for identifying clean development mechanism projects under the Kyoto Protocol. *Energy Policy* 2002; **30**: 73–79.

[7] Shrestha R.M., Shrestha R. Economics of clean development mechanism power projects under alternative approaches for setting baseline emissions. *Energy Policy* 2004; **32:** 1363–1374.

[8] Winkler H., Thorne S. Baselines for suppressed demand: CDM projects contribution to poverty alleviation. *South African Journal of Economic and Management Sciences, SAJEMS* 2002; **5**: 413-429.

[9] Michaelowa A., Hayashi D., Marr M. Challenges for energy efficiency improvement under the CDM – the case of energy efficient lighting. *Energy Efficiency* 2009; **2**: 353-367.

[10] Polimeni J.M., Kozo M., Giampietro M., Alcott B. *The Jevons paradox and the myth of resource efficiency improvements*. London: Earthscan; 2008.

[11] United Nations, Department for Economic and Social Affairs Statistics Division (UN-DESASD). *Handbook of input-output table compilation and analysis*. New York: United Nations; 1999.

[12] Bullard C.W., Penner P.S., Pilati, D.A. Net energy analysis. Handbook for combining process and input-output analysis. *Resources and Energy* 1978; **1**: 267-313.

[13] Lenzen M., Wier M., Cohen C., Hayami H., Pachauri S., Schaeffer R. A comparative multivariate analysis of household energy requirements in Australia, Brazil, Denmark, India and Japan. *Energy* 2006; **31**: 181–207.

[14] Goldar A. Bhanot J., Shimpo K. Prioritizing towards a green export portfolio for India: An environmental input-output approach. *Energy Policy* 2011; **39**: 7036-7048.

[15] Central Statistical Organisation - Ministry of Statistics and Programme Implementation (CSO-MOSPI). *Input Output Transactions Table, 2003-04*. [Online]. Available: http://mospi.nic.in/mospi_new/admin/Publication.aspx

[16] Zimmerman C.C. Ernst Engel's law of expenditures for food. *Quarterly Journal of Economics* 1932; **47**: 78-101.

[17] United Nations Framework Convention on Climate Change (UNFCCC). *Visakhapatnam - Project Design Document form (CDM-SSC-PDD)*. [Online]. Available: http://cdm.unfccc.int/Projects/DB/TUEV-SUED1206629154.85/view

[18] United Nations Framework Convention on Climate Change (UNFCCC). (2009). *Yamuna Nagar & Sonipat - Project Design Document form (CDM-SSC-PDD)*. [Online]. Available: http://cdm.unfccc.int/Projects/DB/TUEV-SUED1238489065.66/view

[19] Central Statistical Organisation - Ministry of Statistics and Programme Implementation (CSO-MOSPI). *NSS 64th round consumer expenditure surveys*. [Database]. Government of India.

[20] Reserve Bank of India. *Publications*. [Online]. Available: http://www.rbi.org.in/scripts/PublicationsView.aspx?id=13628

[21] Intergovernmental Panel on Climate Change (IPCC). *2006 IPCC Guidelines for national greenhouse gas inventories. Volume 2, Energy.* [Online]. Available: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

[22] Johnson E. Goodbye to carbon neutral. *Environmental Impact Assessment Review* 2009; **29**: 165-168.

[23] Pachauri S. *An energy analysis of household consumption. Changing patterns of direct and indirect use in India.* The Netherlands: Springer; 2007.

[24] Balchand K. *Now, Planing Comission lowers the poverty line. The Hindu*. [Online]. Available: http://www.thehindu.com/news/national/article3013870.ece

[25] Sorrell S. The rebound effect: An assessment of the evidence for economy-wide energy savings from improved energy efficiency. London: UK Energy Research Centre (UKERC); 2007.

[26] Herring H., Roy R. Technological innovation, energy efficient design and the rebound effect. *Technovation* 2007; **27**: 194–203.

[27] Institute for Global Environmental Strategies (IGES). *CDM in Asian counties - India.* [Online]. Available: http://www.iges.or.jp/en/cdm/report.html.

[28] Allan G., Hanley N., McGregor P.G., Swales J.K., Turner K. The Macroeconomic Rebound Effect and the UK Economy. Final Report to the Department of Environment Food and Rural Affairs. [Online]. Available: http://ukerc.rl.ac.uk/pdf/ee01015_final_a.pdf

Appendix A. Fuels' combustion emission factors

Fuel type	Net calorific value (MJ/kg)*	Default emission factor ($kgCO_2e/MJ$)**	Emissions due to combustion ($kgCO_2e/kg$)***
Charcoal	29.5	0.117	3.437
Dung cake	11.6	0.108	1.247
Wood	15.6	0.120	1.865
Kerosene	43.8	0.072	3.167
LPG	47.3	0.063	2.991
Petrol	44.3	0.070	3.088
Diesel	43.0	0.074	3.203

*Data from table 1.2 of the IPCC report [21]
**Calculated from the default emission factors for stationary combustion of fuels on a net calorific basis (table 2.5 of the IPCC report [21]). Values of CH_4 and N_2O were transformed to CO_2e by multiplying them times a global warming potential of 21 and 310, respectively (shown values are rounded).
***Resultant from multiplying each fuel's net calorific value times its default emission factor (shown values are rounded).
Note: To transform data of kerosene, petrol and diesel from litters to kilograms, density values of 0.8 kg/Lt (kerosene), 0.7 kg/Lt (petrol) and 0.8 kg/Lt (diesel) were used.

Appendix B. Electricity intensities of Indian commodities

IOTT Code	Commodity	Intensity	IOTT Code	Commodity	Intensity	IOTT Code	Commodity	Intensity
1	Paddy	0.0213						
2	Wheat	0.0270	45	Tobacco products	0.0067	88	Electrical industrial machinery	0.0272
3	Jowar	0.0075	46	Khadi, cotton textiles (handlooms)	0.0303	89	Electrical wires & cables	0.0277
4	Bajra	0.0063	47	Cotton textiles	0.0342	90	Batteries	0.0353
5	Maize	0.0079	48	Woolen textiles	0.0269	91	Electrical appliances	0.0257
6	Gram	0.0064	49	Silk textiles	0.0201	92	Communication equipments	0.0260
7	Pulses	0.0091	50	Art silk, synthetic fiber textiles	0.0301	93	Other electrical machinery	0.0281
8	Sugarcane	0.0098	51	Jute, hemp, mesta textiles	0.0299	94	Electronic equipments (including TV)	0.0251
9	Groundnut	0.0038	52	Carpet weaving	0.0190	95	Ships & boats	0.0203
10	Coconut	0.0041	53	Readymade garments	0.0200	96	Rail equipments	0.0283
11	Other oilseeds	0.0081	54	Miscellaneous textile products	0.0250	97	Motor vehicles	0.0273
12	Jute	0.0029	55	Furniture & fixtures-wooden	0.0136	98	Motor cycles & scooters	0.0349
13	Cotton	0.0095	56	Wood & wood products	0.0120	99	Bicycles, cycle-rickshaw	0.0262
14	Tea	0.0017	57	Paper, paper products & newsprint	0.0310	100	Other transport equipments	0.0328
15	Coffee	0.0058	58	Printing & publishing	0.0214	101	Watches & clocks	0.0131
16	Rubber	0.0045	59	Leather footwear	0.0121	102	Medical, precision&optical instrum.	0.0249
17	Tobacco	0.0040	60	Leather & leather products	0.0129	103	Jems & jewelry	0.0097
18	Fruits	0.0016	61	Rubber products	0.0230	104	Aircraft & spacecraft	0.0149
19	Vegetables	0.0019	62	Plastic products	0.0276	105	Miscellaneous manufacturing	0.0212
20	Other crops	0.0108	63	Petroleum products	0.0148	106	Construction	0.0210
21	Milk & milk products	0.0020	64	Coal tar products	0.0221	107	Electricity	1.1446
22	Animal services (agricultural)	0.0097	65	Inorganic heavy chemicals	0.0315	108	Water supply	0.0194
23	Poultry & eggs	0.0016	66	Organic heavy chemicals	0.0312	109	Railway transport services	0.0517
24	Other livestock prod. & gobar gas	0.0046	67	Fertilizers	0.0217	110	Land transport including via pipeline	0.0115
25	Forestry & logging	0.0018	68	Pesticides	0.0245	111	Water transport	0.0085
26	Fishing	0.0025	69	Paints, varnishes & lacquers	0.0258	112	Air transport	0.0131
27	Coal & lignite	0.0190	70	Drugs & medicines	0.0202	113	Supporting & aux.transport activities	0.0225
28	Natural gas	0.0105	71	Soaps, cosmetics & glycerin	0.0194	114	Storage & warehousing	0.0737
29	Crude petroleum	0.0120	72	Synthetic fibers, resin	0.0208	115	Communication	0.0136
30	Iron ore	0.0184	73	Other chemicals	0.0263	116	Trade	0.0068
31	Manganese ore	0.0026	74	Structural clay products	0.0356	117	Hotels & restaurants	0.0148
32	Bauxite	0.0333	75	Cement	0.0529	118	Banking	0.0064
33	Copper ore	0.0150	76	Other non-metallic mineral prod.	0.0330	119	Insurance	0.0123
34	Other metallic minerals	0.0248	77	Iron, steel & ferro alloys	0.0402	120	Ownership of dwellings	0.0010
35	Lime stone	0.0165	78	Iron & steel casting & forging	0.0435	121	Education & research	0.0017
36	Mica	0.0064	79	Iron & steel foundries	0.0323	122	Medical & health	0.0072
37	Other non metallic minerals	0.0042	80	Non-ferrous basic metals	0.0367	123	Business services	0.0143
38	Sugar	0.0114	81	Hand tools, hardware	0.0255	124	Computer & related activities	0.0042
39	Khandsari, boora	0.0114	82	Miscellaneous metal products	0.0321	125	Legal services	0.0019
40	Hydrogenated oil (vanaspati)	0.0114	83	Tractors & agricultural implements	0.0290	126	Real estate activities	0.0034
41	Edible oils other than vanaspati	0.0101	84	Industrial machinery(food&textiles)	0.0264	127	Renting of machinery & equipment	0.0007
42	Tea & coffee processing	0.0166	85	Industrial machinery(others)	0.0230	128	O.community, social&personal serv.	0.0048
43	Miscellaneous food products	0.0161	86	Machine tools	0.0246	129	Other services	0.0064
44	Beverages	0.0180	87	Other non-electrical machinery	0.0262	130	Public administration	0.0000

Note: Units of all coefficients are kilowatt-hour per Indian Rupee worth of a product at final consumption (kWh/Rs.), except for electricity (sector 107), which is in kilowatt-hour of required generation per kilowatt-hour of final demand (kWh/kWh).
Four decimal digits are shown in order to differentiate among the intensities of all items.